

REPORT DOCUMENTATION PAGE					Form Approved OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY) 01-02-2006		2. REPORT TYPE Final		3. DATES COVERED (From - To) Dec 1st, 2002 - Nov 17th, 2005		
4. TITLE AND SUBTITLE Affordable Cognitive Modeling Authoring Tools using HCI Methods: Worcester Polytechnic Institute Portion				5a. CONTRACT NUMBER		
				5b. GRANT NUMBER N00014-03-1-0221		
				5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S) Heffernan, Neil. T.  Koedinger, Kenneth. R.  Aleven, Vincent				5d. PROJECT NUMBER		
				5e. TASK NUMBER		
				5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Worcester Polytechnic Institute 100 Institute Road, Worcester Polytechnic Institute, Worcester, MA In cooperation with Carnegie Mellon University				8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Program Officer: Harold Hawkins Office of Naval Research 800 North Quincy Street Arlington VA 22217-5660				10. SPONSOR/MONITOR'S ACRONYM(S) ONR		
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION/AVAILABILITY STATEMENT Unlimited Distribution						
13. SUPPLEMENTARY NOTES						
14. ABSTRACT This is a final report for grant N000140310221 in which we report on our work on						
15. SUBJECT TERMS Cognitive Modeling, behavioral modeling, cost-effective						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT  UU	18. NUMBER OF PAGES  4	19a. NAME OF RESPONSIBLE PERSON Neil T. Heffernan	
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (Include area code) 508-831-5569	

Note: Researchers at Carnegie Mellon University (CMU) and Worcester Polytechnic Institute (WPI) conducted the following research collaboratively. This document is the WPI version. Ken Koedinger at CMU is submitting the same final report for the CMU version of the final report.

## **Final Report**

Grant Number: N000140310221

Principal Investigator: Neil T. Heffernan

Institution: Computer Science Department,  
Worcester Polytechnic Institute, Worcester, MA 01609

Grant Title: Affordable Cognitive Modeling Authoring Tools using HCI  
Methods: Worcester Polytechnic Institute Portion

Award Period: Dec 1<sup>st</sup> , 2002- Nov 17<sup>th</sup> , 2005

**20060526027**

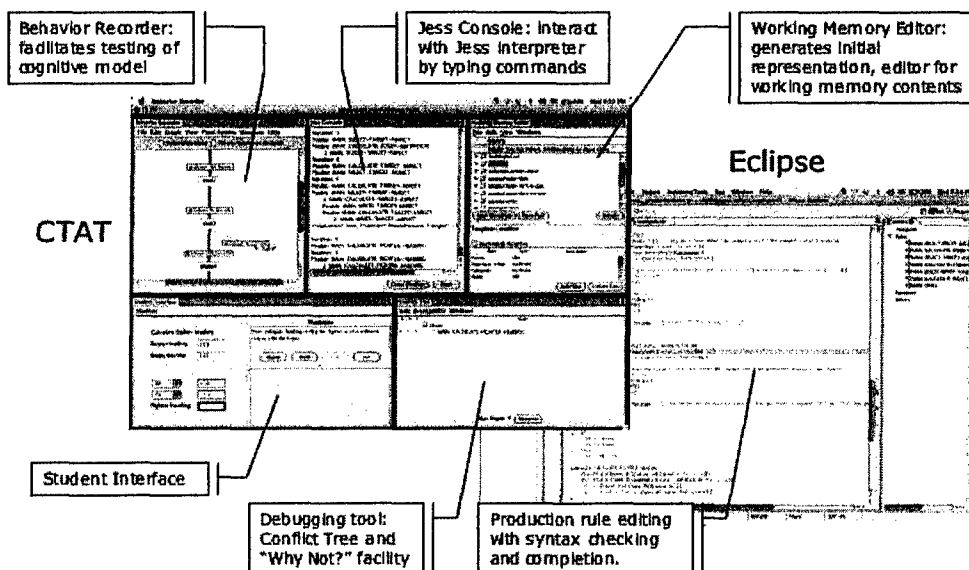
## Objective:

To investigate ways to increase the affordability of human behavioral modeling through development of better software tools to support this task and the gathering of objective evidence that the tools do make modeling more affordable.

## Approach:

We proposed to develop a suite of Cognitive Tutor Authoring Tools (CTAT) to make modeling both *easier and faster* for experienced modelers and *possible* for potential modelers who are not experts in cognitive psychology or artificial intelligence programming. Our concrete goal was to reduce modeling time by a factor of three and to experimentally demonstrate this reduction. We also proposed to push the state of the art in “programming by demonstration” by having our tools induce cognitive rules from demonstrated solutions.

The approach we used was to build a suite of tools, called the Cognitive Tutor Authoring Tools (CTAT), which allow non-programmers to “demonstrate” the behavior they want the system to model. A central tool called the Behavior Recorder records the demonstrated problem steps in a “Behavior Graph,” which may capture multiple paths through a problem scenario, as well as incorrect behavior that needs to be modeled. Behavior Graphs are used in two ways. First, they are used to build what we call “example-tracing tutors,” which are less general than cognitive rule-based tutors but much faster to develop. The second use of these demonstrations is as a guide to help behavioral rule-based modelers do their task. The cognitive modeler uses the Behavior Graphs as test cases to test his/her rules. The CTAT tools are shown below and described in greater detail in Koedinger, Aleven, Heffernan, McLaren, & Hockenberry, 2004; Aleven, Sewall, McLaren, & Koedinger, in press; Aleven, McLaren, Sewall, & Koedinger, in press.



We used these tools to build our own tutors as well as hosting weeklong summer workshops in 2003, 2004, and 2005 in which we freely distributed the tools to researchers and trained them in their use. Over 100 researchers have attended these training and dissemination workshops and several other academic groups are now using the tools. We have also made our tools freely

available from a website (<http://ctat.pact.cs.cmu.edu/>). We estimate that there are currently between 100 and 200 users of CTAT.

### **Accomplishments:**

We were able to show that our tools can be used to build many different rule-based cognitive models, such as a Warrior Simulator at Fort Benning (Livak & Heffernan, 2004), a Logic Tutor for internal use at CMU, and a Genetics tutor.

In preliminary controlled experiments involving basic Cognitive Tutor development tasks, we found efficiency gains due to CTAT of 1.4 to 2 times faster (Aleven, McLaren, Sewall & Koedinger, 2006). We also demonstrated across 4 different behavioral modeling projects that our tools created example-tracing tutors that drastically reduced modeling costs (Koedinger, Aleven, Heffernan, McLaren, & Hockenberry, 2004; Heffernan, Turner, Lourenco, Macasek, Nuzzo-Jones, Koedinger, 2006). Not only did we reduce the time dramatically (averaging a reduction of over a factor 5), we also reduced the experience level modelers needed.

Finally, we pushed the state of the art in data mining and machine learning support to help rule-writers (McLaren et al 2005; Harrer et al, 2005; McLaren et al, 2004b; McLaren et al, 2004a; Jarvis, Nuzzo-Jones, & Heffernan, 2004; Matsuda, Cohen, and Koedinger, 2005a; 2005b; 2005c).

### **Conclusions**

We have made excellent progress toward creating and demonstrating affordable behavior modeling through development and evaluation research on the Cognitive Tutor Authoring Tools. The central approach has been to use human-computer interaction, data mining, and machine learning techniques to create software components, smart interfaces and underlying intelligence, that speed the process of behavior modeling. Critical to our success has been creating a large user community that provides both realistic user tests and vote-with-your-feet evidence that CTAT is effectively reducing behavior-modeling costs. The 200 users of CTAT represent the largest number of users of any technology in the AHBM program. We have also provided reasonable evidence of affordability improvements.

### **Significance**

Cognitive models are used successfully throughout the Armed Forces as well as in educational and training software. However, cognitive models have traditionally been very expensive to build. This small project has produced valuable knowledge about methods that can be used to make modeling more cost effective. This project has also created a specific set of tools (CTAT) that embodies some of this knowledge, and that set of tools has led to the cost-effective creation of many new cognitive models. These models in turn lead to more knowledge as exhibited by the many peer-reviewed papers produced under this grant or related to this grant.

### **Publications**

- Aleven, V., McLaren, B. M., Sewall, J., and Koedinger, K. R. (in press). The Cognitive Tutor Authoring Tools (CTAT): Preliminary Evaluation of Efficiency Gains; Accepted for presentation at the 8th International Conference on Intelligent Tutoring Systems, Jhongli, Taiwan, June 26-30, 2006.
- Aleven, V., Sewall, J., McLaren, B. M., & Koedinger, K. R. (in press). Rapid authoring of intelligent tutors for real-world and experimental use. Accepted for presentation at the The 6th IEEE International Conference on Advanced Learning Technologies (ICALT 2006).
- Harrer, A., McLaren, B. M., Walker, E., Bollen, L., and Sewall, J. (2005) Collaboration and Cognitive Tutoring: Integration, Empirical Results, and Future Directions. In the Proceedings of the 12th

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- Heffernan N.T., Turner T.E., Lourenco A.L.N., Macasek M.A., Nuzzo-Jones G., Koedinger K.R., The ASSISTment Builder: Towards an Analysis of Cost Effectiveness of ITS creation, Accepted by FLAIRS2006 sponsored of American Association of Artificial Intelligence, Florida, USA (2006).
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- Koedinger, K. R., Aleven, V., & Heffernan, N. T. (2003) Toward a Rapid Development Environment for Cognitive Tutors. 12th Annual Conference on Behavior Representation in Modeling and Simulation. Simulation Interoperability Standards Organization.
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- McLaren, B. M., Bollen, L., Walker, E., Harrer, A., and Sewall, J. (2005). Cognitive Tutoring of Collaboration: Developmental and Empirical Steps Toward Realization, In the *Proceedings of the Conference on Computer Supported Collaborative Learning (CSCL-05)*, Taipei, Taiwan in May/June 2005.
- McLaren, B. M., Koedinger, K. R., Schneider, M., Harrer, A., and Bollen, L. (2004a). Bootstrapping Novice Data: Semi-Automated Tutor Authoring Using Student Log Files; In the *Proceedings of the Workshop on Analyzing Student-Tutor Interaction Logs to Improve Educational Outcomes*, Seventh International Conference on Intelligent Tutoring Systems (ITS-2004), August 2004.
- McLaren, B. M., Koedinger, K. R., Schneider, M., Harrer, A., and Bollen, L. (2004b) Toward Cognitive Tutoring in a Collaborative, Web-Based Environment; *Proceedings of the Workshop of AHCW 04*, Munich, Germany, July 2004.
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- Razzaq, L., Feng, M., Nuzzo-Jones, G., Heffernan, N.T., Koedinger, K. R., Junker, B., Ritter, S., Knight, A., Aniszczuk, C., Choksey, S., Livak, T., Mercado, E., Turner, T.E., Upalekar, R., Walonoski, J.A., Macasek, M.A., Rasmussen, K.P. (2005). The Assistment Project: Blending Assessment and Assisting. In C.K. Looi, G. McCalla, B. Bredeweg, & J. Breuker (Eds.) *Proceedings of the 12th Artificial Intelligence In Education*, 555-562. Amsterdam: ISO Press.
- Razzaq L., Heffernan, N.T. (in press) Scaffolding vs. Hints in the Assistment System, 8<sup>th</sup> Annual International Conference on Intelligent Tutoring Systems. Taiwan
- Turner, T.E., Macasek, M.A., Nuzzo-Jones, G., Heffernan, N.T., Koedinger, K. (2005). The Assistment Builder: A Rapid Development Tool for ITS. In Looi, McCalla, Bredeweg, & Breuker (Eds.) *Proceedings of the 12th Artificial Intelligence In Education*, Amsterdam: ISO Press. p. 929-931.

## Patents

WPI's Heffernan and CMU's Koedinger filed for a U.S. Pat. No. 60/699,624 related to the WPI version of pseudo-tutor construction.

## Awards:

This grant funding helped lead to many other successful projects that used the results of this ONR grant.

- Heffernan was awarded an NSF CAREER award half way through this grant<sup>1</sup>.
- Koedinger was awarded a \$25 million NSF Science of Learning Center grant that is now supporting the use, and further development, of the authoring tools this grant produced.
- Heffernan and Koedinger were awarded \$1.4 millions dollars to use the techniques developed during the grant to cost-effectively create a complex new cognitive model, and tutoring systems used by thousands of students inside of 2 year.<sup>2</sup>
- Heffernan and colleagues at WPI were awarded a grant to further the learning sciences<sup>3</sup>
- Heffernan and colleagues at Sonalysts were funded to demonstrate application of these techniques to help Fort Benning enable "Warrior Tutoring" inside of their simulations at Fort Benning.
- Koedinger received a 2-year grant from the Grable foundation to support the further development of the CTAT tool suite. Grant title: Authoring Cognitive Tutors, Number: 11655-1-1030164, Start: 4/12/04, End: 5/31/06

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<sup>1</sup> "Learning about Learning" NSF CAREER award to Heffernan. \$600,000.

<sup>2</sup> "Using Web-Based Cognitive Assessment Systems for Predicting Student Performance on State Exams" US Dept of Education: Institute of Education Sciences . \$1.4 million.

<sup>3</sup> Title: "Fellowships in CS to support the learning sciences and security". US Dept of Ed: Graduate Assistance in Areas of National Need (GAANN). \$804,940. PI: Ward, Heffernan, Agu and Heineman